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Monte Carlo Simulations of the Structures and Optical Absorption Spectra of AlAr_N Clusters

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Monte Carlo Simulations of the Structures and Optical Absorption Spectra of AlAr_N Clusters

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ABSTRACT

Classical Monte Carlo simulation techniques have been used in conjunction with recently devised spectral methods for constructing the ground and low-lying excited state potential energy surfaces of atomic aggregates to predict the structures and optical absorption spectra of AlAr_N clusters. The new spectral theory properly accounts for the change in electronic state character encountered in avoided crossings of diatomic adiabatic states and of the associated AlAr_N aggregate states, in contrast to strictly pairwise-additive methods such as the Balling and Wright model, which constitute special limiting cases of the general spectral theory. The AlAr_N simulations seek to understand several key issues regarding the experimental spectroscopic study of AlAr_N clusters [James M. Spotts, Chi-Kin Wong, Matthew S. Johnson, and Mitchio Okumura, *Proceedings of the HEDM Contractors' Conference, 5-7 June 1996*], such as: (1) the location of the Al atom (surface or interior), (2) the role of the 4s and 4p states of Al in the putative 3p \rightarrow 3d transition, and (3) the origin of the spectral red shifts and splittings as a function of cluster size. In the case of the Al-Ar diatom, an avoided crossing between the π components of the 3d and 4p manifolds is expected to play a crucial role in the observed absorption spectra of AlAr_N clusters. The (17s12p5d4f)/[7s6p4d3f] atomic natural orbital basis set of Widmark et al. (supplemented with diffuse (1s1p1d1f) functions), in conjunction with internally contracted multi-reference configuration interaction (MRCI) calculations from a [6331] (3e- in 13 orbitals) state-averaged complete active space reference wavefunction, was used to calculate the Al-Ar diatomic potential energy curves which correlate with the 3p, 4s, 3d, and 4p atomic states of Al. The Ar-Ar interaction energies were computed using the "HFDB2" potential of Aziz and Slaman. Detailed comparisons are made of the calculated spectra with the available measured data.

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SPECTRAL THEORY OUTLINE

Diatom wavefunctions written as superposition of atomic product states (direct product of Al and Ar atomic states):

$$\begin{array}{c} \text{Al} \qquad \qquad \text{Ar} \\ \{3P, 4S, 3D, 4P\} \otimes \{1S_0\} \end{array}$$

$$\begin{aligned} \Phi &= \{ 3P_{+1} \bullet^1 S_0, 3P_0 \bullet^1 S_0, 3P_{-1} \bullet^1 S_0, 4S \bullet^1 S_0, 3D_{+2} \bullet^1 S_0, \dots, 4P_{-1} \bullet^1 S_0 \} \\ &= \{ 3P_{+1}, 3P_0, 3P_{-1}, 4S, 3D_{+2}, \dots, 4P_{-1} \} \end{aligned}$$

$$\Psi = \{ X^2\Pi, A^2\Sigma, B^2\Sigma, \dots, (3)^2\Pi \}$$

$$\Phi = U^t \Psi$$

Hamiltonian for atomic cluster given by:

$$H = \sum H^{(k)} + H^{(SO)}$$

$$H^{(k)} = D^t U^t E U D$$

$H^{(SO)}$ = spin-orbit coupling operator for Al atom.

E = diagonal matrix of diatomic interaction energies (X,A,B,C,... state energies)

U = unitary matrix which transforms from the diatomic basis to the atomic-product basis.

D = transformation matrix connecting the “rotated” and laboratory coordinate systems.

Atomic state mixing parameters U_{ij} obtained from eigenvectors of the diatomic and “spectral-product” transition moment matrices: $\mathbf{U} = \mathbf{U}_d (\mathbf{U}_{sp})^t$, where \mathbf{U}_d and \mathbf{U}_{sp} obey the following:

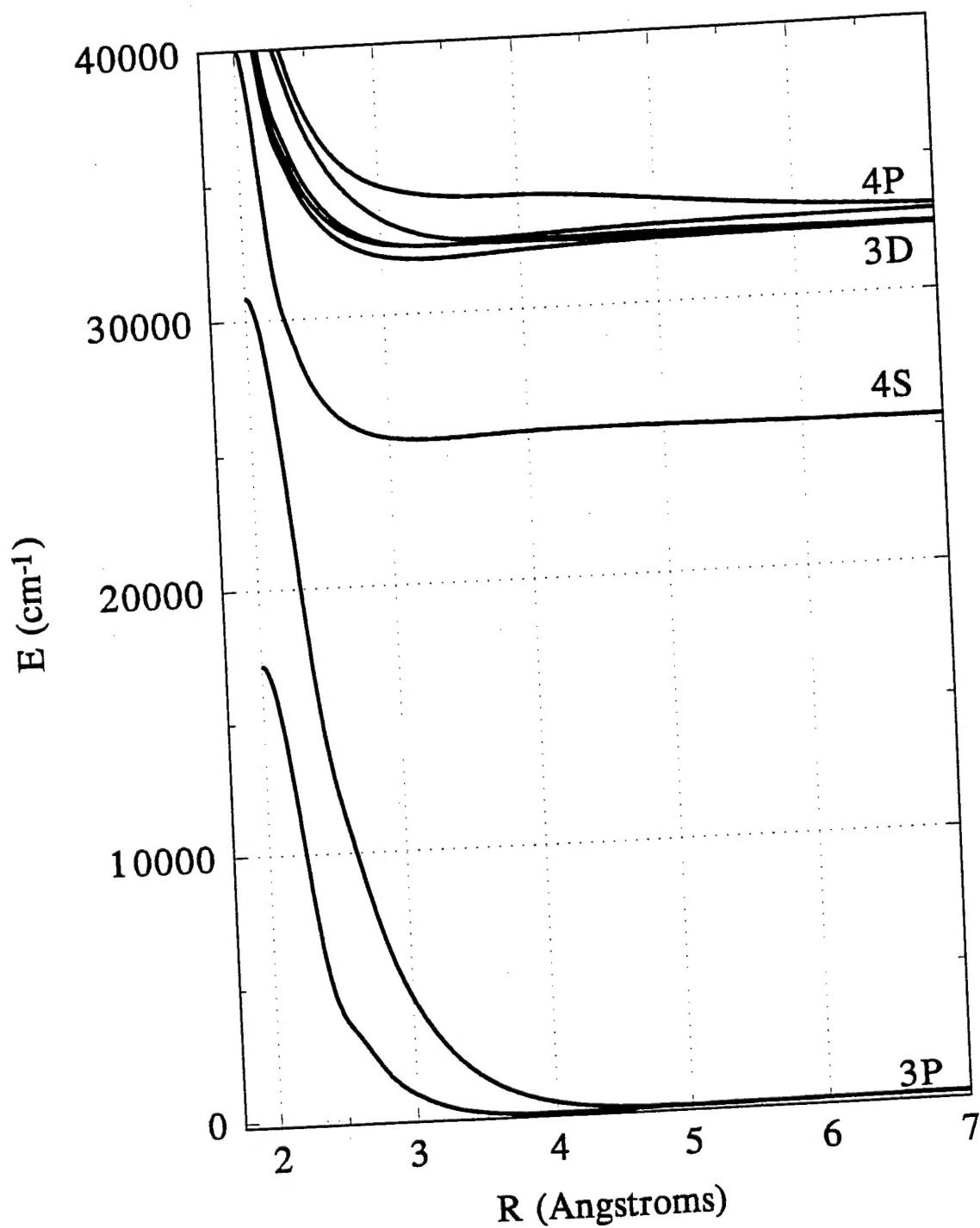
$$\lambda_d = (\mathbf{U}_d)^t \mu(\mathbf{R}) \mathbf{U}_d$$

and

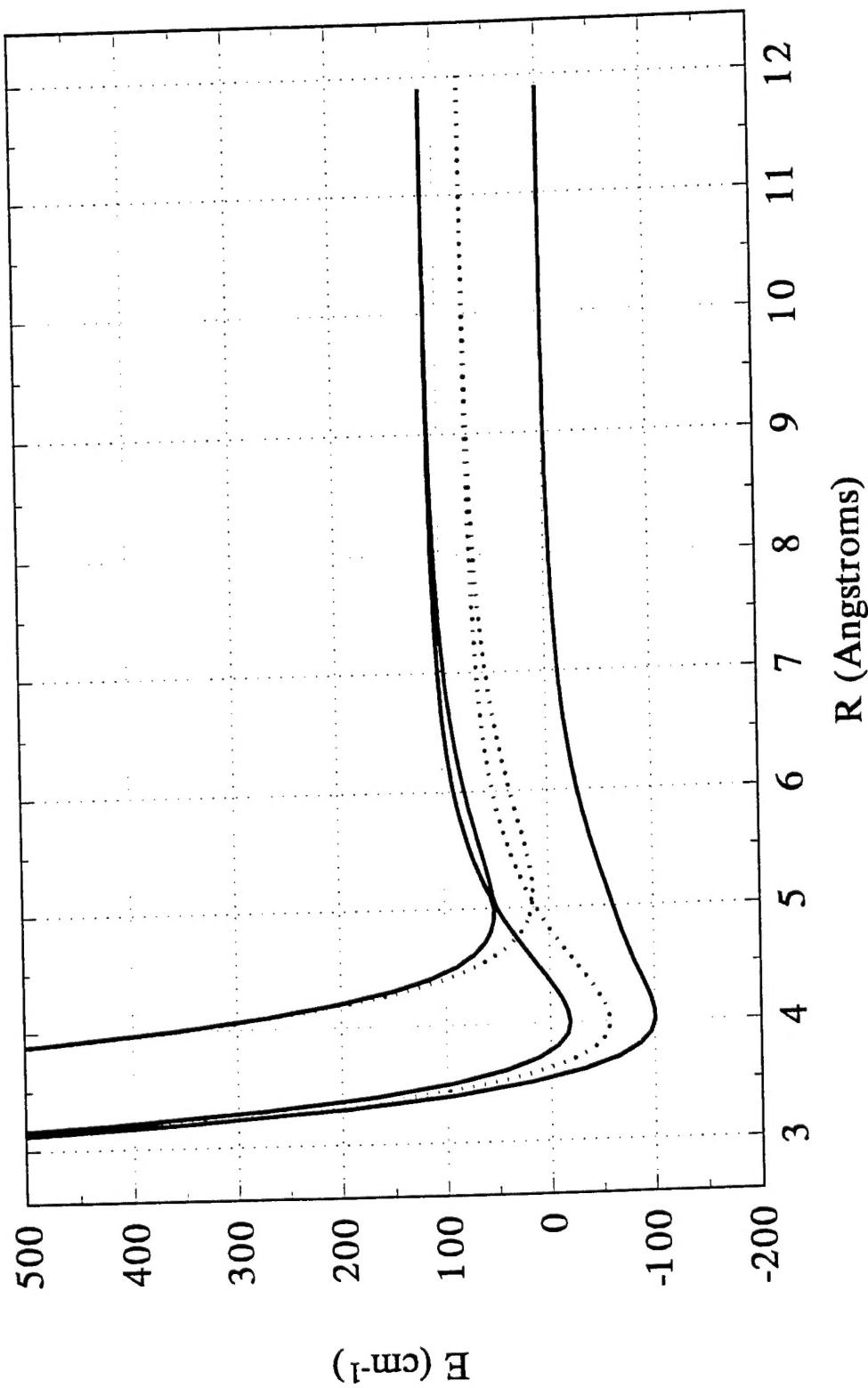
$$\lambda_{sp} = (\mathbf{U}_{sp})^t \mu_0(\mathbf{R} \rightarrow \infty) \mathbf{U}_{sp}$$

This is “exact” only in the case where $\lambda_{sp} = \lambda_d$.

AlAr MRCI Potentials

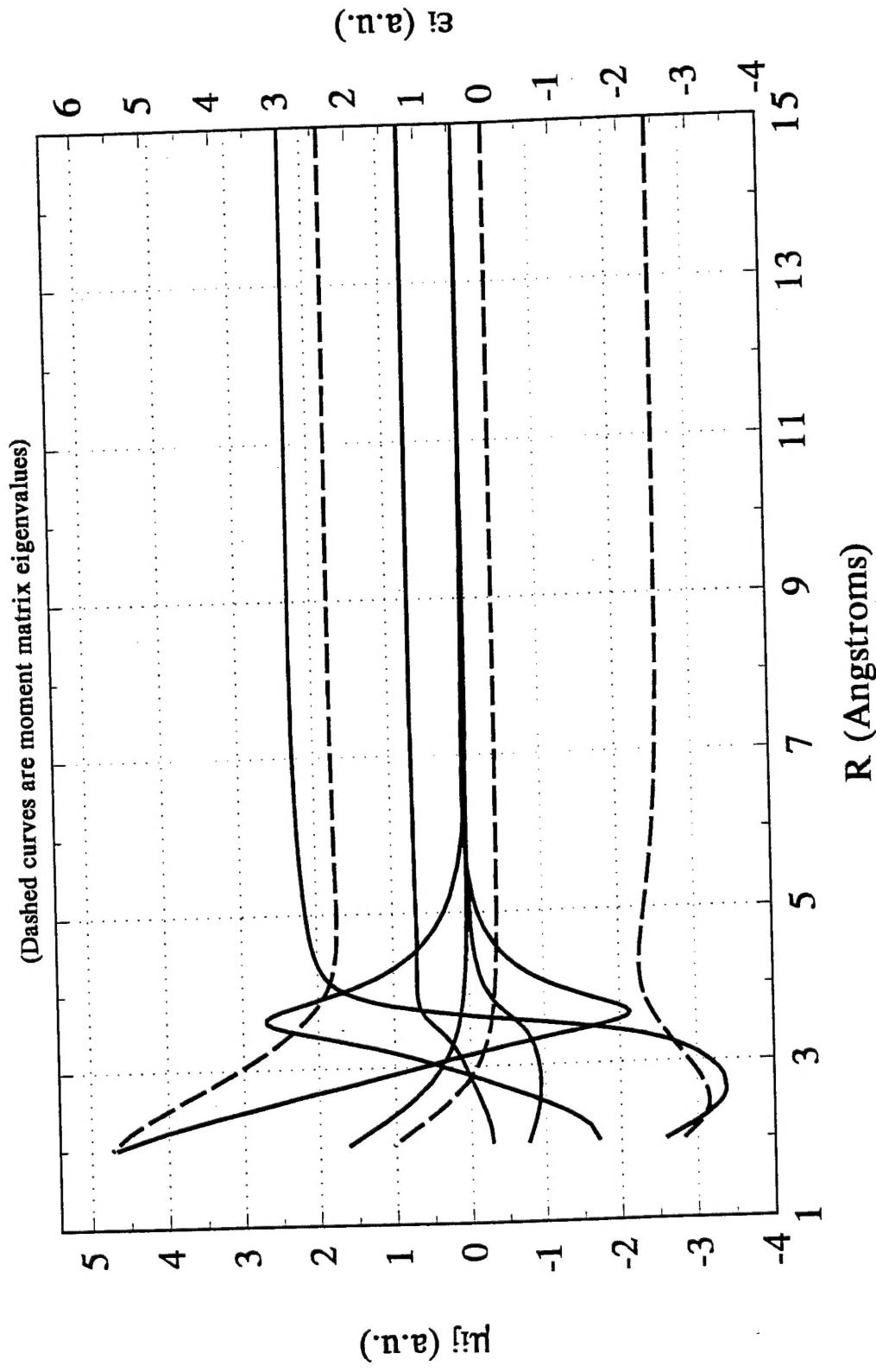


AlAr MRCl Potentials
"3P" curves

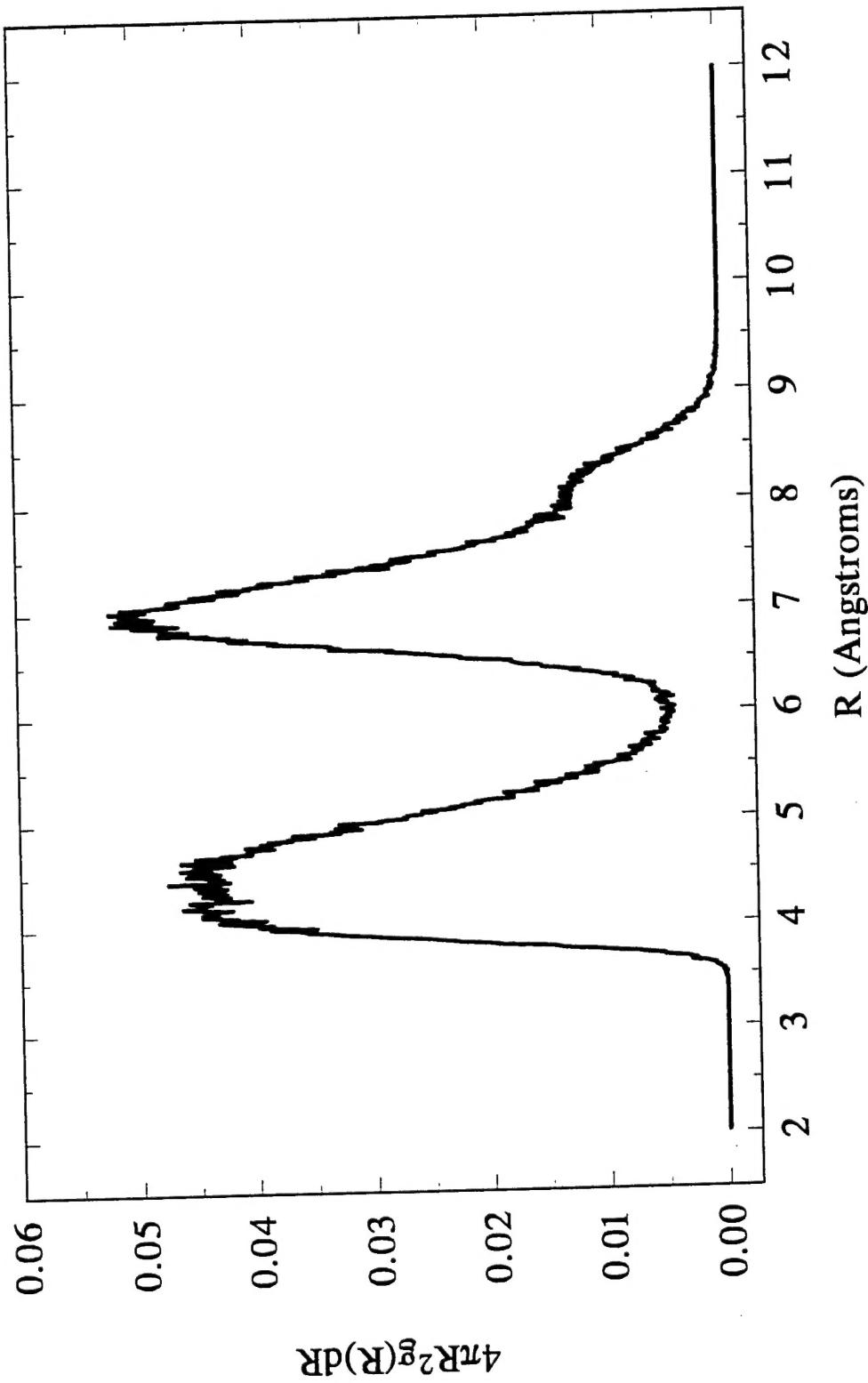


AlAr MRCl Transition and Dipole Moments

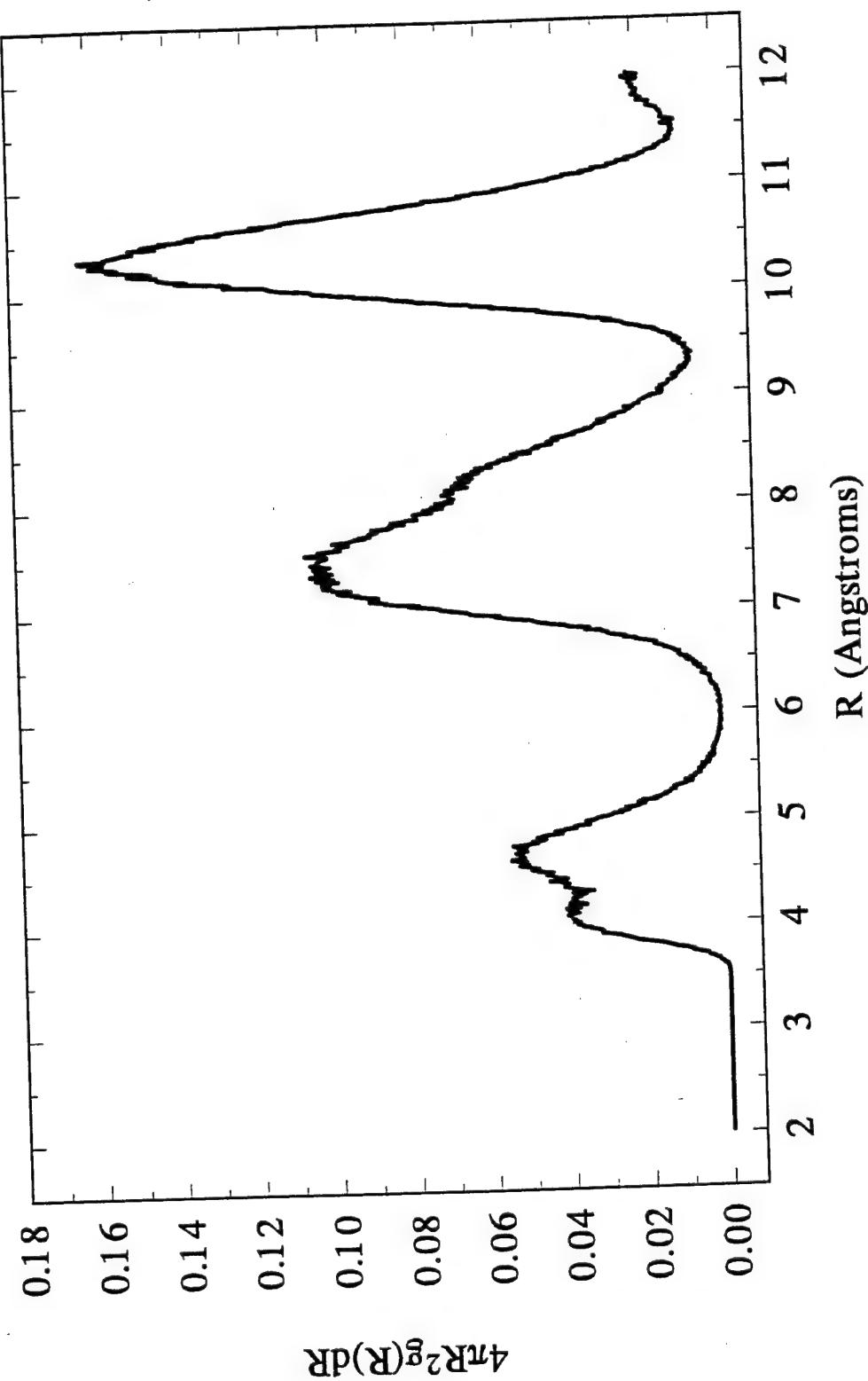
$\Pi \rightarrow \Pi$ Moments



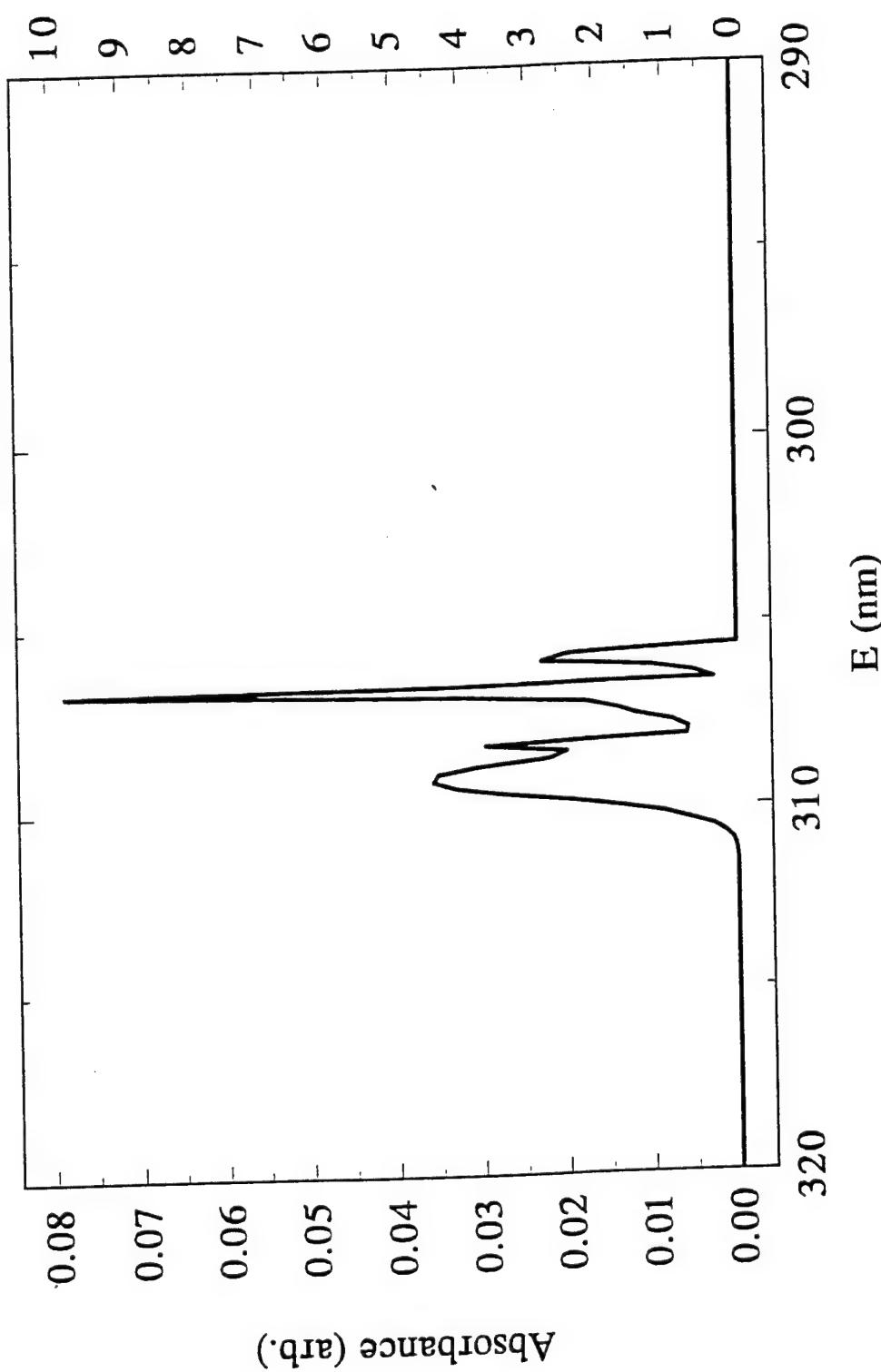
AlAr12 Radial Probability Distribution Function (RPDF)
 $T = 30\text{K}$



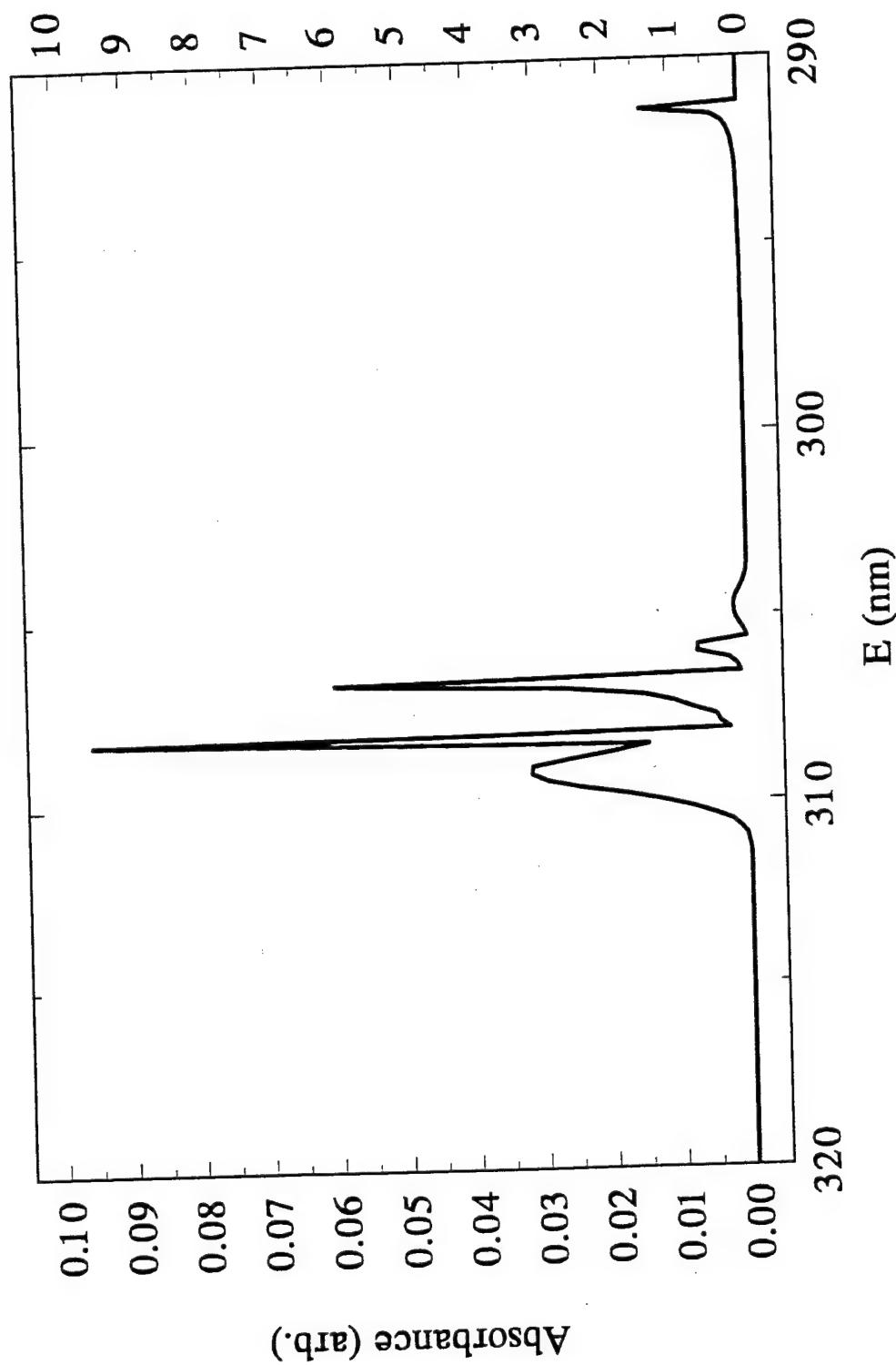
AlAr54 Radial Probability Distribution Function (RPDF)
 $T = 30\text{K}$



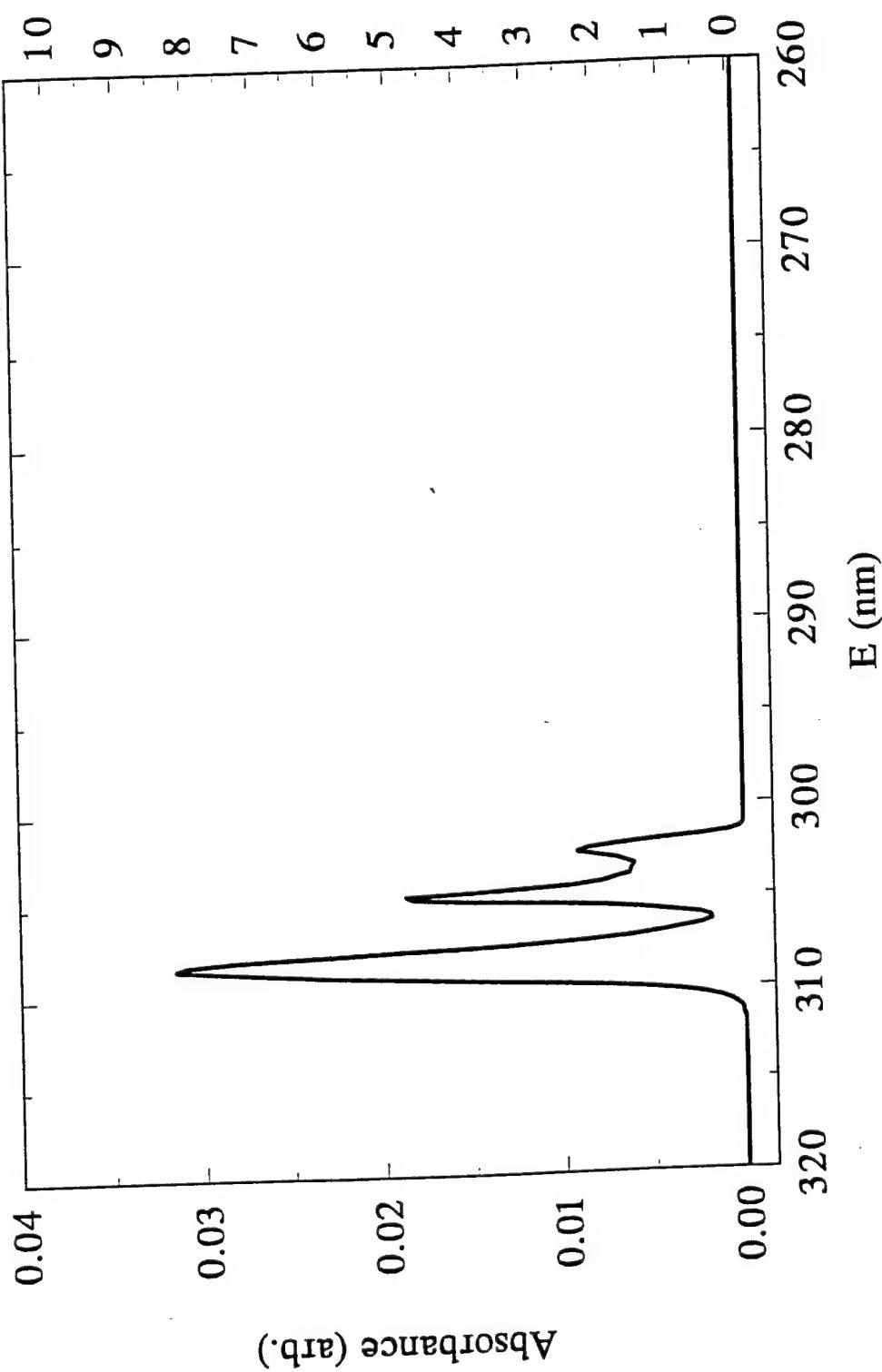
AlAr Absorption Spectrum
 $T = 20K$, B&W limit



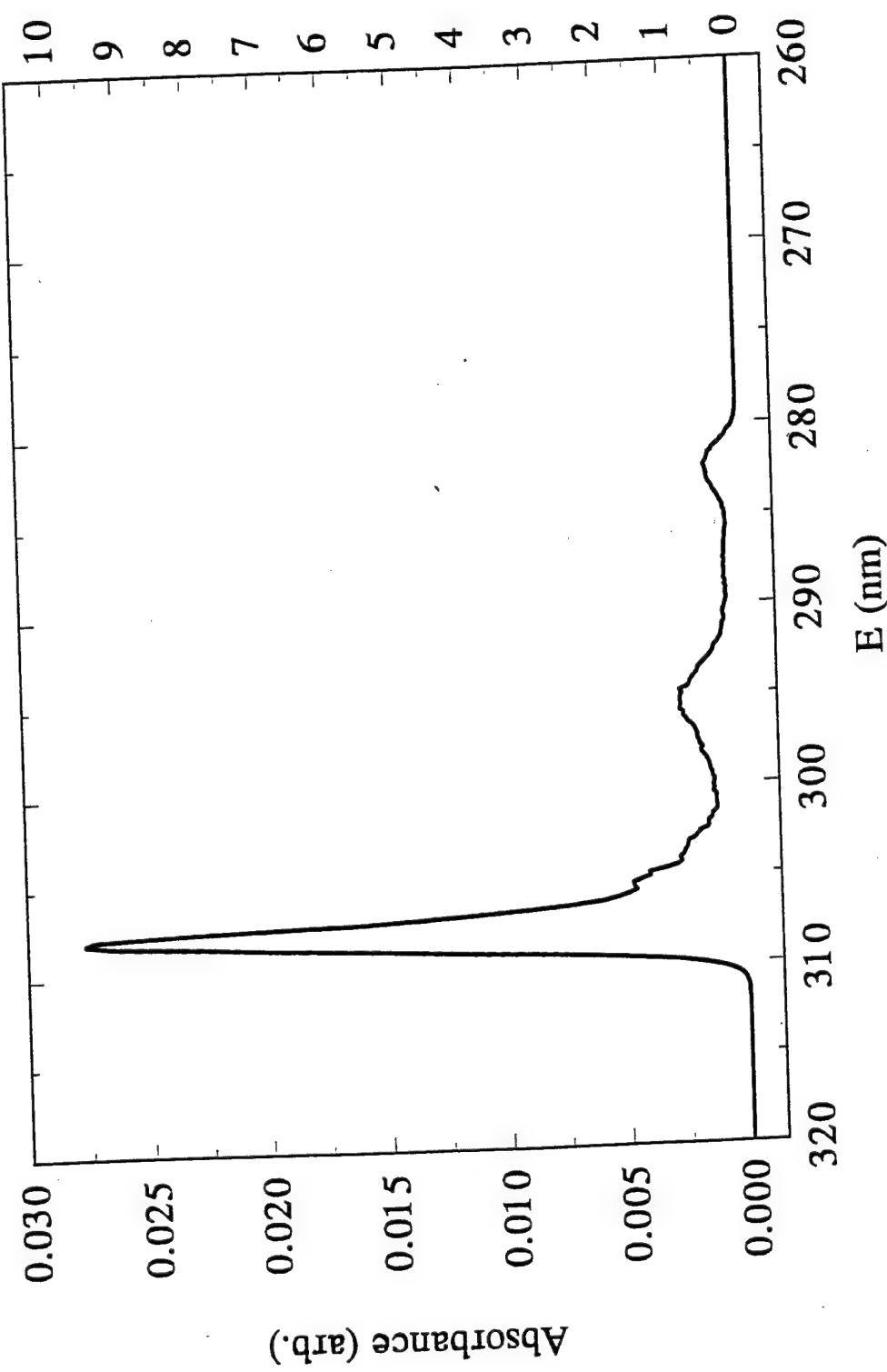
AlAr Absorption Spectrum
 $T = 20K, ST$



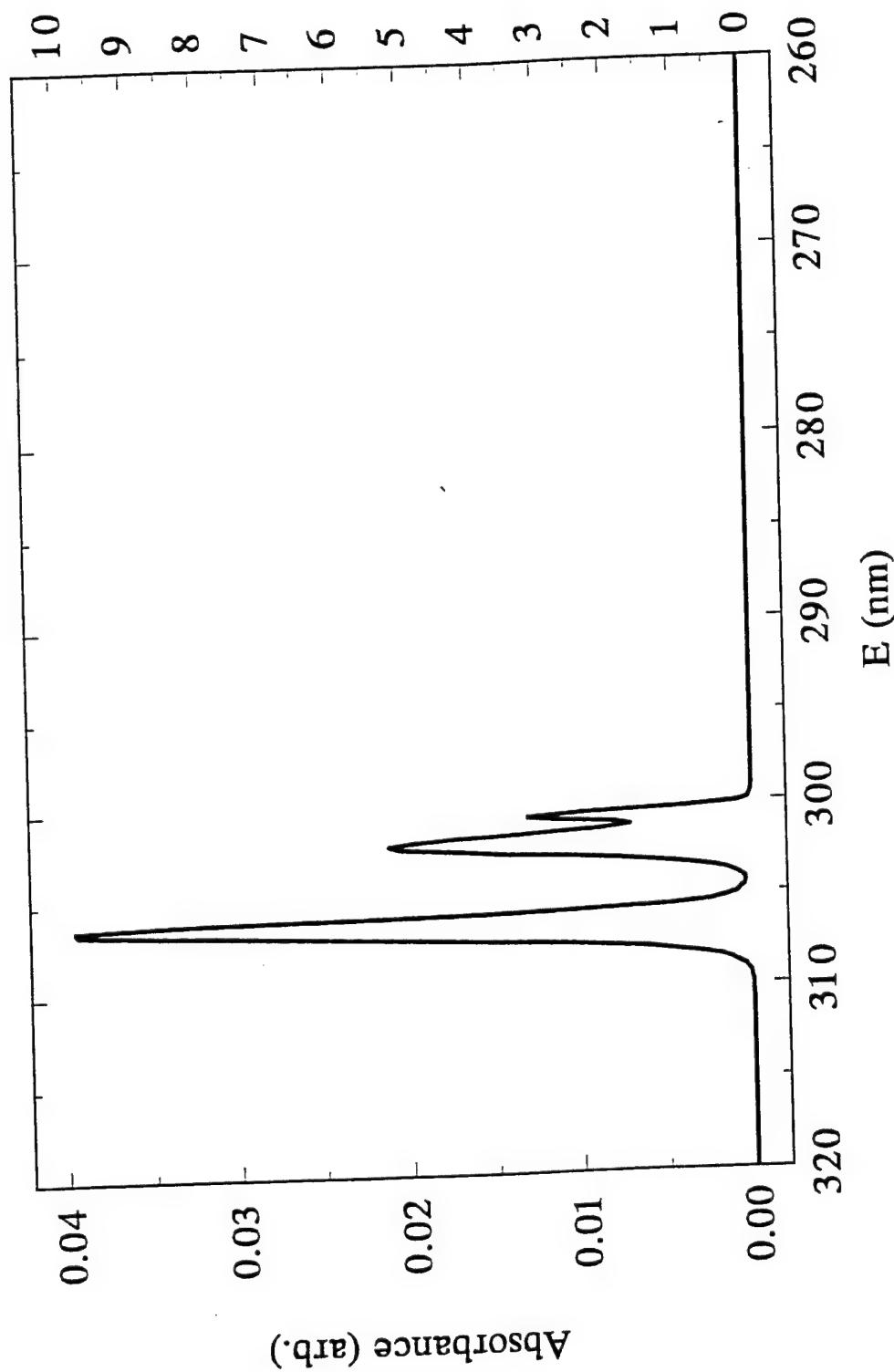
AlAr₆ Absorption Spectrum
T = 30K, B&W limit



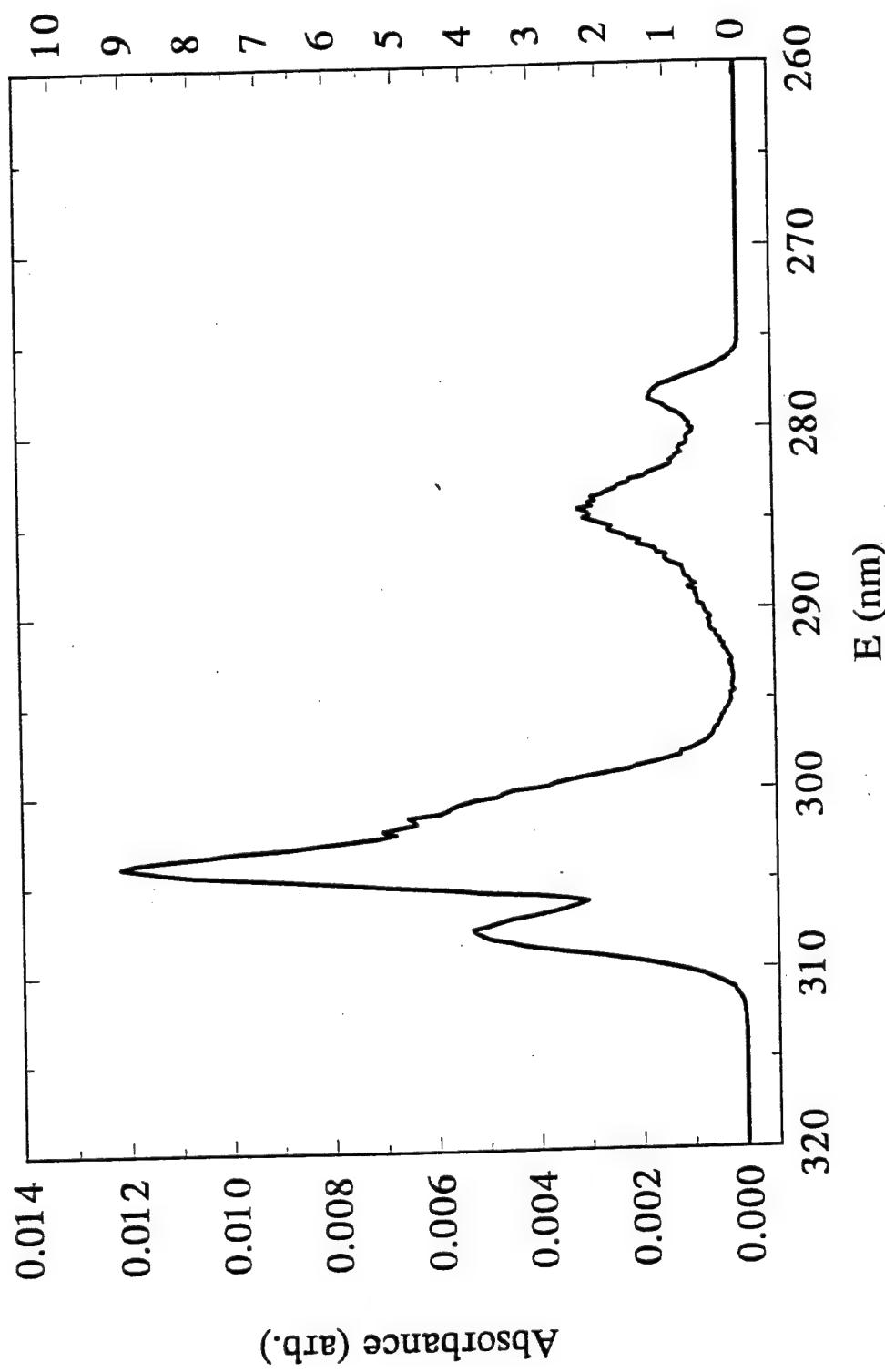
AlAr₆ Absorption Spectrum
 $T = 30K, ST$



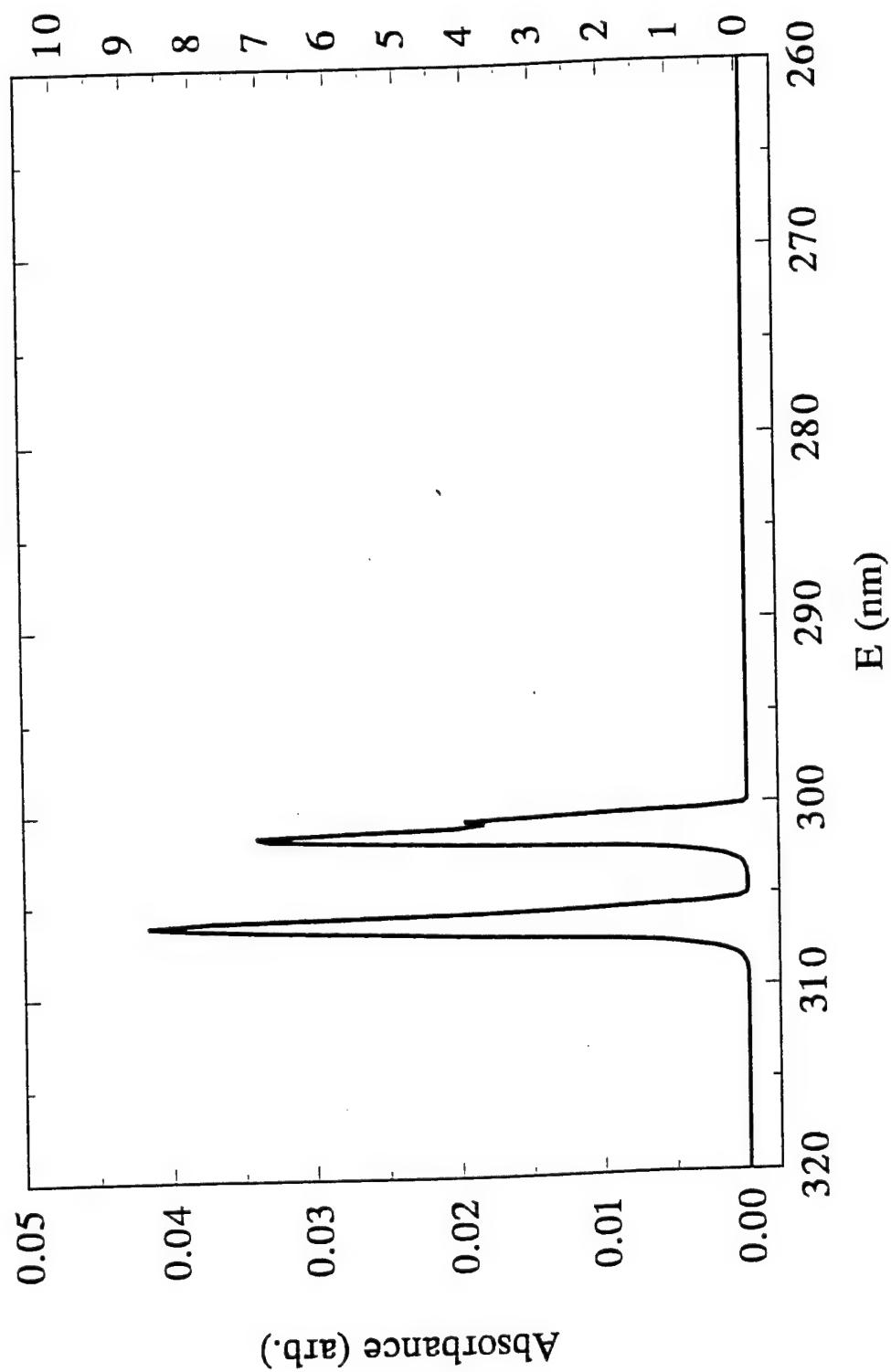
AlAr₁₂ Absorption Spectrum
T = 30K, B&W limit



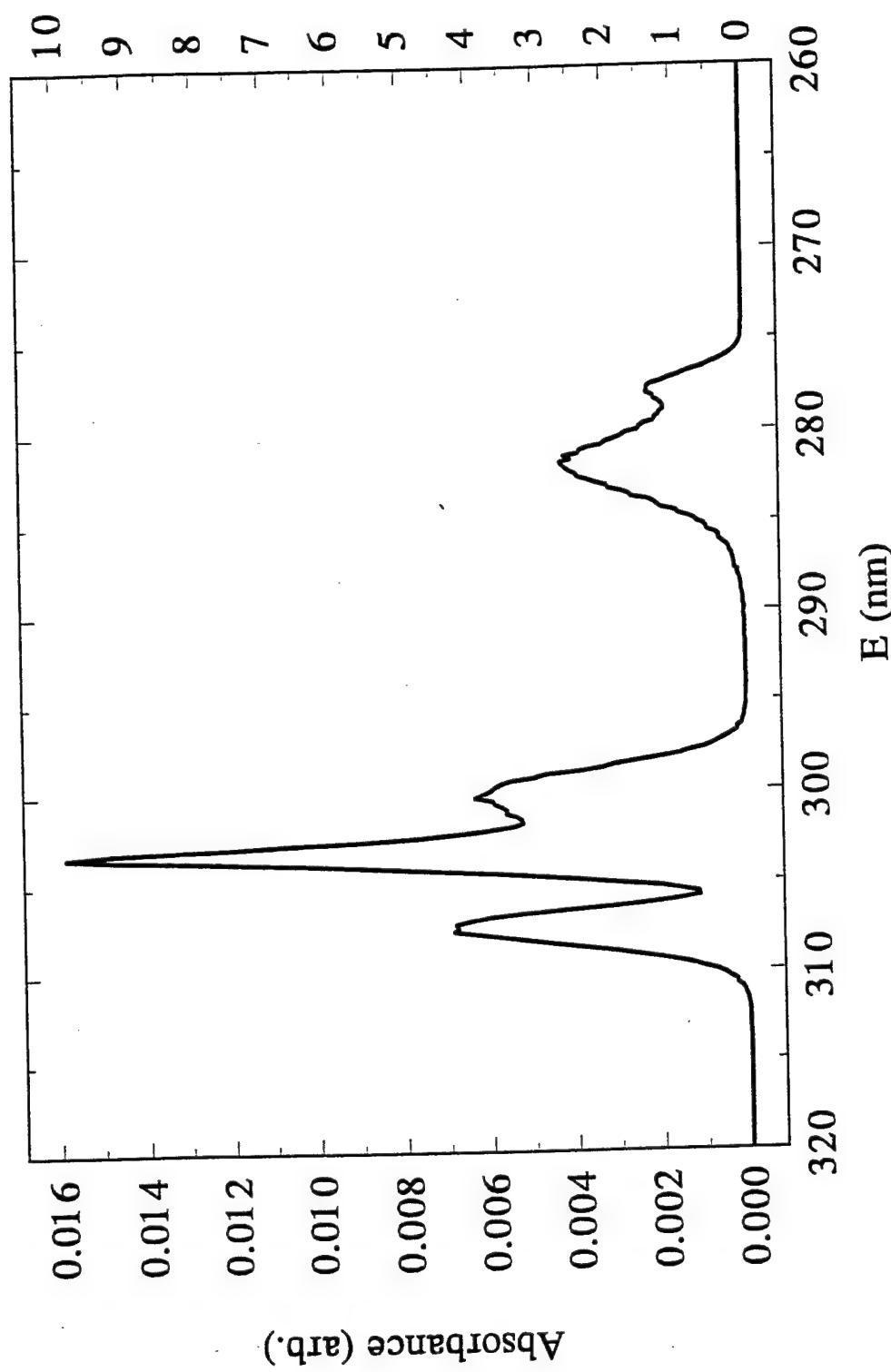
Al₁Ar₁₂ Absorption Spectrum
T = 30K, ST



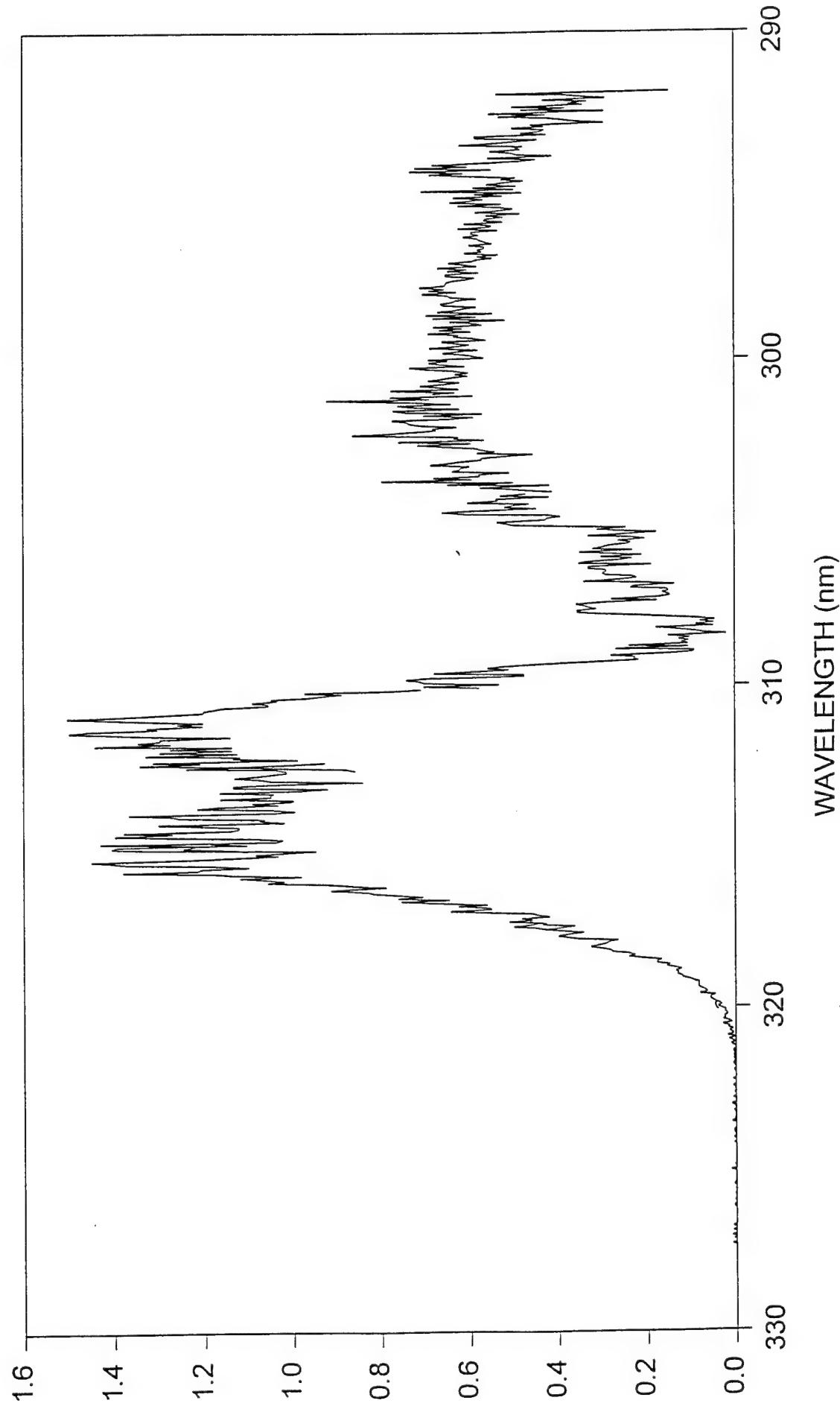
AlAr54 Absorption Spectrum
 $T = 30K$, B&W limit



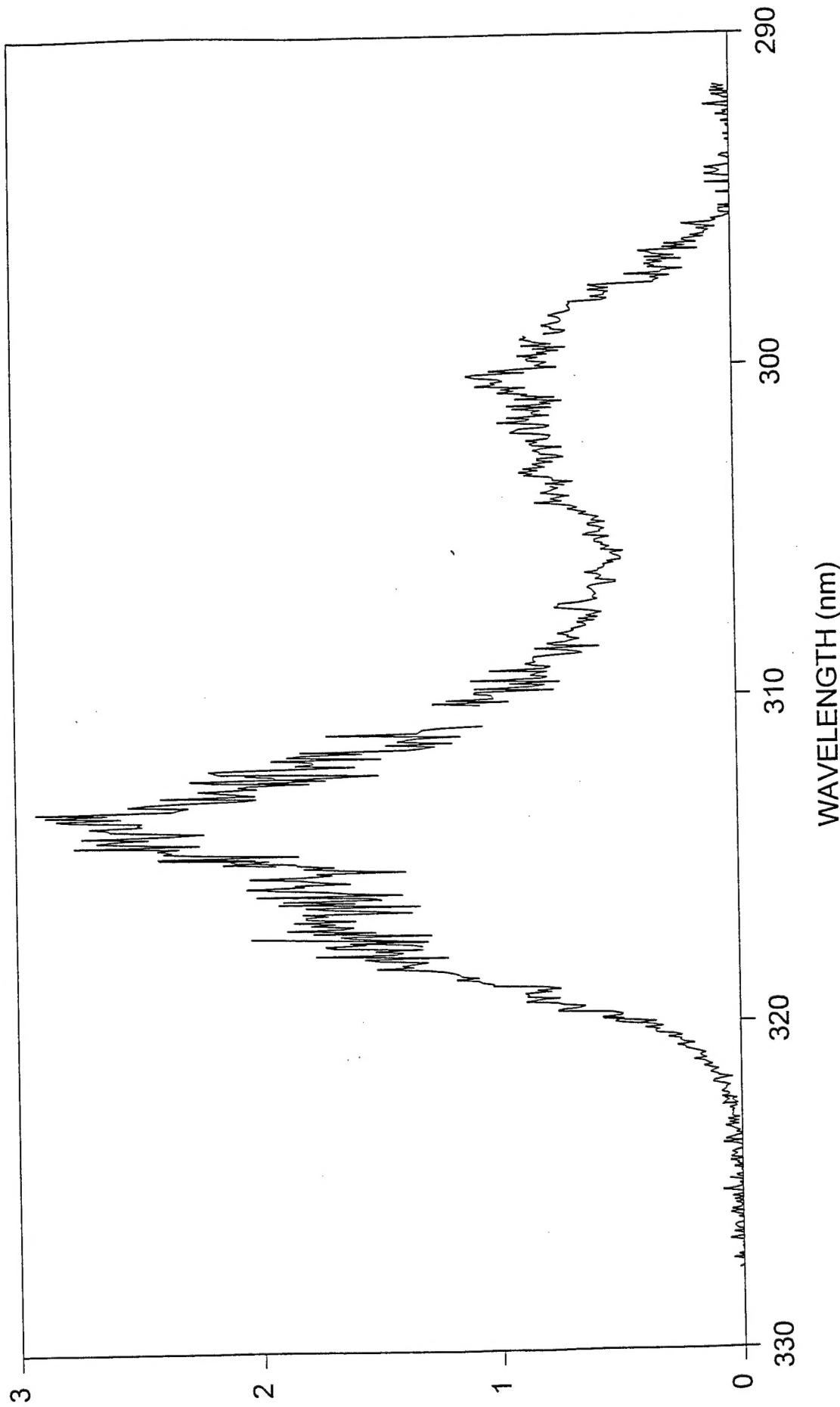
AlAr54 Absorption Spectrum
 $T = 30\text{K}, \text{ST}$



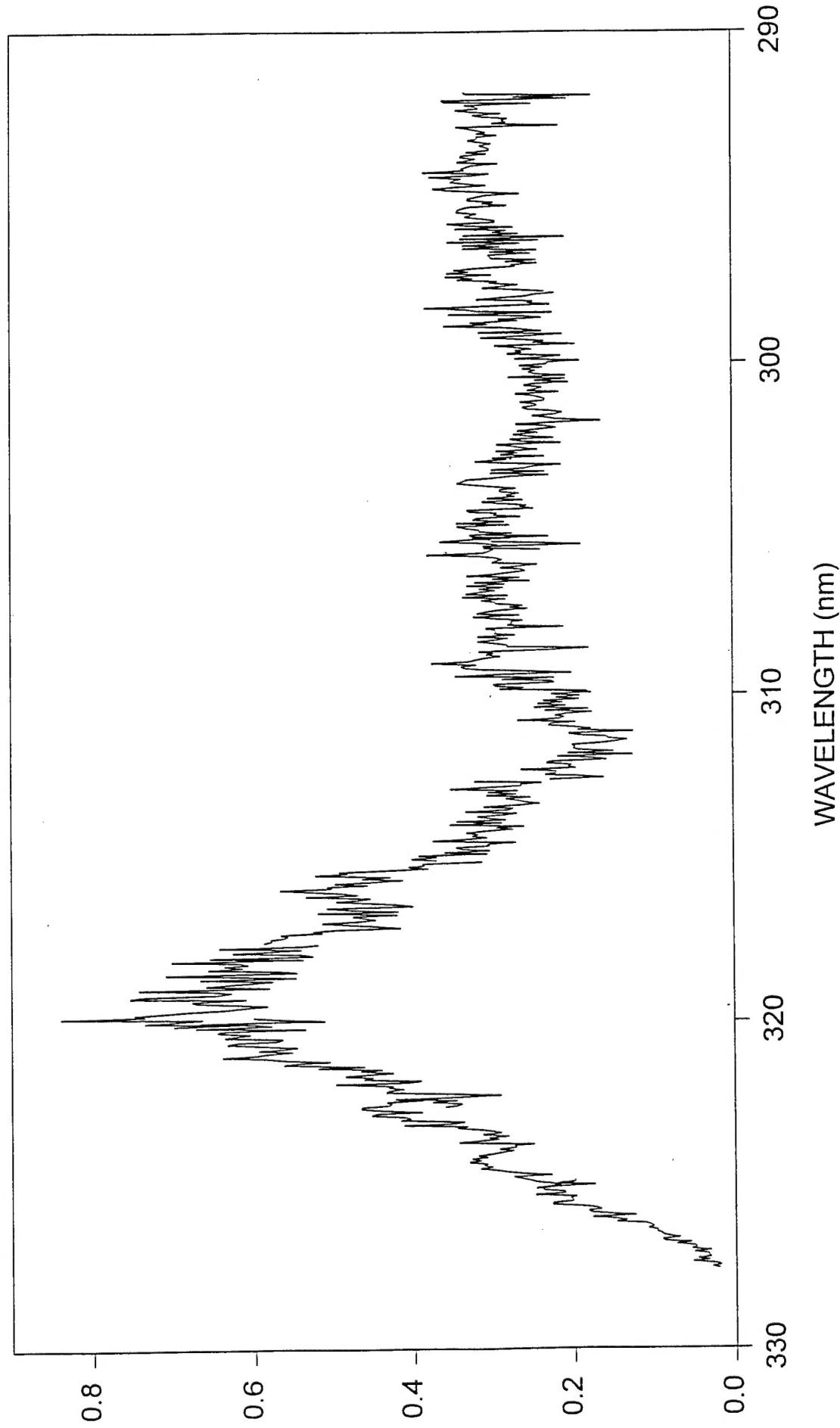
AlAr₆



AlAr₁₂



ΔAr_{54}



CONCLUSIONS

1. Al is located on surface of clusters.
2. For AlAr, absorptions in the 311-306 nm range are due primarily to $3p \rightarrow 3d$ transitions. Absorption peaks at 305 and 292 nm are due to $3d \rightarrow 4p$ transitions.
3. In the B&W limit, the $3d-4p$ transitions are missing in the simulated spectra due to improper description of the avoided crossing between the $3d, 4p \Pi$ states.
4. Simulated spectra do not reproduce observed red-shift in $3p \rightarrow 3d$ absorptions. This may be due to missing non-additive effects in the ground state potential energy surface of the clusters.

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